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European Patent Office  
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(11)

EP 0 723 033 A1

(12)

## EUROPEAN PATENT APPLICATION

(43) Date of publication:  
24.07.1996 Bulletin 1996/30

(51) Int Cl.<sup>6</sup>: C22F 1/04, C22F 1/043

(21) Application number: 96200060.0

(22) Date of filing: 12.01.1996

(84) Designated Contracting States:  
DE FR GB

(30) Priority: 19.01.1995 EP 95200134  
12.05.1995 EP 95201243

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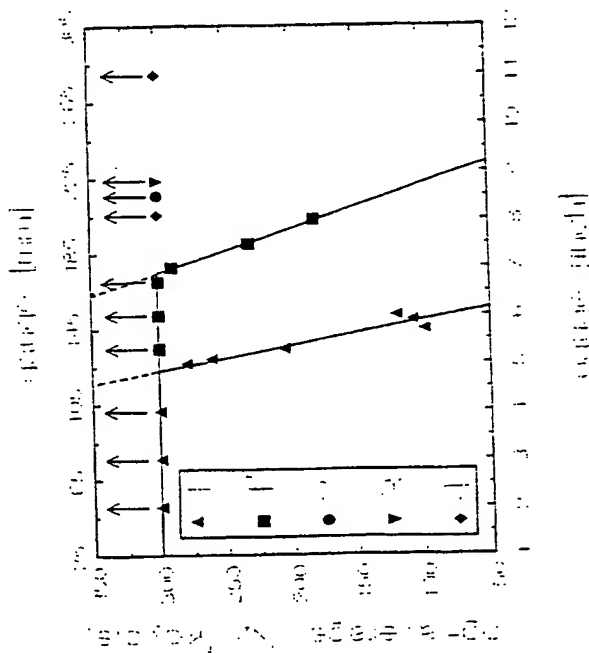
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### (54) Process for manufacturing thick aluminium alloy plate

(57) Process for manufacturing thick aluminum alloy plate having improved properties comprising the step of hot deformation of an ingot, characterized in that the hot deformation comprises the combination of

- hot rolling operations, and
- forging operations

in which at least one of the hot rolling and forging operations is at least partly executed in the width direction.



## Description

The invention relates to a process for manufacturing thick aluminum alloy plate having improved properties comprising the step of hot deformation of an ingot.

An important field of application of thick aluminum alloy plate is aircraft and aerospace applications. For those applications in fatigue properties, representing the number of starts and landings of the airplane, as well as the mechanical properties of the thick plate are of major importance. With improved properties of the thick plate weight reductions can be obtained. For other applications the mechanical properties are important as well.

The invention provides improved fatigue properties as well as improved mechanical properties but will be primarily described in terms of fatigue properties. For the purpose of this application thick plate will be plate with a thickness of at least 2 inches. It is known in the art that the fatigue properties are reduced at larger gauges. In the present state of the art a thickness of 6 inches is about the limit in which acceptable fatigue properties can be produced.

US 5,277,719 discloses that the fatigue properties in a 5.7 inch thick plate can be improved by forging in the thickness direction of the plate with a thickness reduction of at least 30%.

In NL9400939 it has been described that the fatigue properties of a 6 inch thick plate can be improved by certain measures during casting of the ingot and/or during the hot rolling thereof.

In aircraft industries there is a need for plate of more than 6 inches having good properties to fabricate certain parts therefrom in a cheap way instead of using forged parts.

A first objection of the invention is to provide a process for manufacturing thick aluminum alloy plate having improved properties.

A second object of the invention is to provide thick aluminum alloy plate with a thickness of more than 2 inches having improved properties.

A third object of the invention is to newly provide thick aluminum alloy plate with a thickness of more than 6 inches having excellent properties.

These objects are obtained by a process of manufacturing thick aluminum alloy plate in which the hot deformation comprises the combination of

- hot rolling operation, and
- forging operations

in which at least one of the hot rolling and forging operations is at least partly executed in the width direction.

As may be seen from the test results the fatigue properties obtained by the process of invention are dramatically improved. It is thought that this is a result of executing at least partly at least one of the hot rolling and forging operations in the width direction. When thick plate is manufactured in a conventional way i.e. by hot rolling, the properties in the width direction, the so-called long transfer (LT) direction, are worse than the properties in the length direction. By forging the micro-structure and therewith the properties are generally improved. However, by executing one of the hot deformation operations in the width direction the properties in the width direction are particularly improved. By the combination of forging and hot rolling and by executing one of these operations in the width direction a very considerable improvement of the properties is obtained.

In a first embodiment of the invention the hot deformation comprises:

- firstly hot rolling in the width direction, followed by
- forging in the thickness direction.

In this embodiment the hot deformation in the width direction is given in a first step of hot deformation by rolling and the second step of hot deformation comprises forging in the thickness direction.

In a second embodiment of the invention the hot deformation comprises:

- firstly forging in the thickness direction, followed by
- hot rolling in the width direction.

In this embodiment the sequence of the steps of hot deformation of the first embodiment is reversed. In this second embodiment the hot deformation may be followed by hot rolling in the length direction. In both the first and second embodiment the hot deformation in the width direction is by rolling and the hot deformation by forging in the thickness direction is limited to 30% to allow for a considerable hot deformation in the width direction.

In a third embodiment of the invention the hot deformation comprises

- firstly forging in width direction, followed by

- hot rolling.

In this embodiment the hot deformation in the width direction is, contrary to the first and second embodiment, by forging. Preferably the forging in width direction results in a thickness dimension which is larger than the width direction, thereby forming a new width direction being the former thickness direction, and a new width direction being the former thickness direction. Thereby the hot rolling may be in the new width direction and may be followed by hot rolling in the length direction.

Preferably with the second and third embodiment the thickness reduction by hot rolling is in the range of 10 to 50%. In this way, starting from usual ingot dimensions, thick plates of 6" and more are obtained.

In another aspect the invention is embodied in a thick aluminum alloy plate having a thickness in the range of 2-12 inches and having a log-average fatigue life at 35 ksi of at least 150 kcycles and preferably having a log-average fatigue life at 35 ksi of at least 300 kcycles and a thickness in the range of 6-12 inches. In still another aspect the invention is embodied in a thick aluminum alloy plate having a thickness in the range of 2-12 inches and having a fracture toughness in dependency of its thickness as given by the following formula:  $K_{Ic} T - L \geq -1.2 X G + 31.2$  in which  $K_{Ic} T - L$  is the fracture toughness in the long transfer direction expressed in ksi inch<sup>0.5</sup> and G is the thickness of the plate expressed in inches. The values for the fracture toughness according to this aspect of the invention are to be found at the right side of the sloped line in Fig. 5.

The aluminum alloy of the thick plate is preferably an alloy of the AA 2000 or AA 7000 series. More preferably the alloy is AA 7010, AA 7049, AA 7149, AA 7050, AA 7150, AA 7055, AA 7064, AA 7075, AA 7175, AA 7475, AA 7076, AA 7178. More preferably the alloy contains by weight 5-9% Zn, 0.3-3% Cu, 1-3% Mg, max. 0.4% Si, max. 0.6% Fe, max. 0.5% Mn, max. 0.3% Zr, max. 0.3% Cr, max. 0.3% V, max. 0.3% Nb, max. 0.3% Hf and max. 0.5% Sc.

The invention will be elucidated by means of the drawing.

Fig. 1 shows the lifetime of thick plate obtained by various processes in dependency of the thickness of the plate at 35 ksi.

Fig. 2 shows the ultimate tensile strength of thick plate obtained by various processes in dependency of the thickness of the plate.

Fig. 3 shows the tensile yield strength of thick plate obtained by various processes in dependency of the thickness of the plate.

Fig. 4 shows the elongation of the thick plate obtained by various processes in dependency of the thickness of the plate.

Fig. 5 shows the fracture toughness of thick plate obtained by various processes in dependency of the thickness of the plate.

#### Example

AA 7050 T 7451 thick plates were manufactured by casting ingots having after scalping and sawing a thickness of about 400 mm, a width in the range of 1070 to 1470 mm and a length in the range of 1700 to 3300 mm, homogenization and preheating prior to hot deformation and solutionizing, quenching, stress relieve and ageing.

In process no. 1 a thick plate with a thickness of 6.0 inches was manufactured in a conventional way by hot rolling only.

In process no. 1' a thick plate with a thickness of 6.7 inches was manufactured also by hot rolling only. In process no. 1' the measures disclosed in NL 9400939 during casting and hot rolling were applied.

In process no. 2 a thick plate with a thickness of 8.5 inches was manufactured by firstly hot rolling an ingot in the width direction to an intermediate thickness of 288 mm, cooling to room temperature, reheating and forging in the thickness direction to a final thickness of 8.5 inches. The thickness reduction by forging was less than 30%.

In process no. 3 a thick plate with a thickness of 8.8 inches was manufactured by firstly forging an ingot in the thickness direction from 400 to 320 mm (thickness reduction about 20%), cooling to room temperature, reheating and hot rolling in the width direction to a thickness of 280 mm (thickness reduction of about 12%) and finally hot rolling in the length direction to a thickness of 8.8 inches.

In process no. 4 a thick plate with a thickness of 11.0 inches was manufactured by firstly forging an ingot in the width direction from 400 x 1300 (thickness x width) into 800 x 400 (new width x new thickness), cooling to room temperature, reheating and hot rolling in the length direction to a thickness of 11.0 inches.

Smooth axial fatigue tests were performed in accordance with ASTM E466 at a stress level of 35 and 40 ksi (241 and 275 MPa), respectively, using a stress ratio of  $R = 0.1$  and a frequency of 20 Hz. Testing conditions were dry laboratory air (relative humidity 30-50%) and room temperature. The specimens were excised from the mid-width and mid-thickness position in the LT-direction with a parallel gauge length of 2 inches (50.8 mm) and a gauge diameter of 0.5 inches (12.7 mm). The minimum and log-average of fatigue life for a set of 4 specimens per plate are given in table 1 and figure 1 for 35 ksi and in table 2 for 40 ksi respectively. The tests were usually terminated at 300.000 cycles if

failure did not occur. Maximum Stress: 35 ksi

Property		Process No. and Gauge [inches]				
		No. 1 6.0	No. 1' 6.7	No. 2 8.5	No. 3 8.8	No. 4 11.0
minimum fatigue life per lot	[cycles]	101.010	300.000	300.000	300.000	300.000
log-average fatigue life per lot	[cycles]	119.801	300.000	300.000	300.000	300.000
number of runouts		0	4	4	4	4

Table 1: Comparison of LT smooth axial fatigue properties of thick 7050 T745X plate when fabricated using different processes: maximum applied stress: 35 ksi, testing as per ASTM E466, testing position: mid-width and mid-thickness, specimens: gauge length = 2", gauge diameter = 0.5", number of specimens tested: 4 per lot: tests were terminated at 300,000 cycles, if failure did not occur.

Maximum Stress: 40 ksi

Property		Process No. and Gauge [inches]				
		No. 1 6.0	No. 1' 6.7	No. 2 8.5	No. 3 8.8	No. 4 11.0
minimum fatigue life	[cycles]	81.378	145.518	300.000	140.241	300.000
log-average fatigue life	[cycles]	92.143	233.656	300.000	162.733	300.000
number of runouts		0	2	4	0	4

Table 2: Comparison of LT smooth axial fatigue properties of thick 7050 T745X plate when fabricated using different processes: maximum applied stress: 40 ksi, testing as per ASTM E466, testing position: mid-width and mid-thickness, specimens: gauge length = 2", gauge diameter = 0.5", number of specimens tested: 4 per lot, tests were terminated at 300,000 cycles, if failure did not occur.

From tables 1 and 2 it appears that the lifetimes of the plates made by the processes no. 2, 3 and 4 in accordance with the invention are all better than the lifetime of the plate made in the conventional way of process no. 1. This also holds true for the plate made by the process no. 1' as disclosed in NL 9400939. However, from table 2 it appears that the plate of process no. 3 is worse than the plates of processes no. 2 and 4. This is attributed to the very limited hot deformation in the width direction given in the example process no. 3. From table 2 it seems that the plate of process no. 3 is even worse than process no. 1', but this is due to the fact that it is also much thicker. As will be discussed later on it can be concluded from Fig. 1 that process no. 3 generally results in a much better fatigue performance than process no. 1'.

In the processes 2, 3 and 4 the hot deformation was executed to obtain thick plates of 8.5, 8.8 and 11.0 inches respectively but it is evident that the hot deformation in processes 2, 3 and 4 is not limited to such thicknesses and can be varied to obtain smaller gauges of 6 inches and less having improved fatigue and mechanical properties.

It is also evident that the processes 2, 3 and 4 of the example may be varied in a considerable degree also giving improved properties as long as those variations satisfy the condition that at least one of the hot rolling and forging operations are at least partly executed in the width direction.

In Fig. 1 the lifetime results obtained by applicant at 35 ksi of thick plates manufactured by the processes 1, 1', 2, 3 and 4 are brought together. Symbols relate to the processes mentioned. Fig. 1 contains not only results obtained by the example but also further results for various thicknesses.

It is observed that the log-average values of the conventional process no. 1 shows a sharp breakdown at a thickness of about 6 inches. In fact from the state of the art, there are no test values known for a thickness beyond 6 inches. The horizontal line of process no. 1 at 300 kcycles represents that the tests were terminated at 300 kcycles. Actual values are unknown but are above 300 kcycles as indicated by arrows. As a first approximation the sloped line of process no. 1 might be extrapolated as indicated by the dotted line to represent those unknown values.

Apparently it is not possible to obtain plates with an acceptable lifetime by process 1 with a thickness beyond 6 inches.

The sloped line representing process 1' in accordance with NL 9400939 represents already a substantial improve-

ment for thick plates up to about 9 inches.

Fig. 1 shows clearly improvement of fatigue properties achieved by processes no. 2, 3 and 4 resulting in log-average values of over 300 kcycles at 35 ksi for plates 8.5, 8.8 and 11 inches thick respectively. This means that the decline in lifetime as with processes 1 and 1' is for process 2 beyond a thicknesses of 8.5 inches, and for processes 3 and 4 beyond thicknesses of 8.8 and 11 inches respectively.

As mentioned above not only the fatigue properties, but also the mechanical properties are improved by the process of the invention. This is shown in the figures 2, 3, 4 and 5 relating to the ultimate tensile strength UTS, the tensile yield strength TYS, the elongation and the fracture toughness  $K_{Ic}$  respectively all in the LT, i.e. the width direction for thick aluminum alloy plate of process number 4. In each of the figures there is shown with a sloped line the value of the respective mechanical property according to the state of the art represented by process number 1 in dependency of the plate thickness. It appears that the mechanical properties of the thick plate of process number 4 are greatly improved relative to the state of the art as far as the elongation and toughness is concerned (see Fig. 4 and 5) and to a lesser extent for the strength values (see Fig. 2 and 3).

## Claims

1. Process for manufacturing thick aluminum alloy plate by hot deformation of an ingot, wherein the hot deformation comprises the combination of

performing at least one hot rolling operation, and  
performing at least one forging operation, wherein at least one of said hot rolling and forging operations is at least partly executed in the width direction of the ingot, with the proviso that, in the case where forging in the width direction is followed by hot rolling, the forging in the width direction results in a final thickness dimension which is larger than the final width dimension.

2. Process for manufacturing thick aluminum alloy plate by hot deformation of an ingot, wherein the hot deformation comprises the combination of

performing at least one hot rolling operation, and  
performing at least one forging operation, wherein at least one of the hot rolling and forging operations is at least partly executed in the width direction of the ingot, and  
wherein the manufactured plate has a thickness in the range 2 to 12 inches (5 to 30 cm) and a log-average fatigue life at 35 ksi of at least 150 kcycles.

3. Process according to claim 2 wherein the manufactured plate has a log-average fatigue life at 35 ksi of at least 300 kcycles.

4. Process according to any one of claims 1 to 3 wherein said hot deformation comprises

(a) the step of hot rolling in the width direction, followed by  
(b) the step of forging in the thickness direction:

5. Process according to claim 4, wherein in said step (b) the thickness reduction is less than 30%.

6. Process according to any one of claims 1 to 3 wherein said hot deformation comprises

(a) the step of forging in the thickness direction, followed by  
(b) the step of hot rolling in the width direction.

7. Process according to claim 6 wherein said step (b) is followed by

(c) hot rolling in the length direction.

8. Process according to claim 6, wherein in said step (a) the thickness reduction is in the range of 10 to 30%.

9. Process according to claim 6, wherein the thickness reduction by hot rolling is in the range of 10 to 50%.

10. Process according to any one of claims 1 to 3 wherein said hot deformation comprises

(a) the step of forging in width direction, followed by

(b) the step of hot rolling

wherein said step (a) results in a final thickness dimension which is larger than the final width direction, thereby forming a new width direction being the former thickness direction, and a new thickness direction being the former width direction.

11. Process according to claim 10 wherein said step (b) comprises the step of (b1) hot rolling in said new width direction,

12. Process according to claim 11 wherein said step (b) further includes, following said step (b1), the step of (b2) hot rolling in the length direction.

13. Process according to claim 10 wherein in said step (a), the thickness dimension in said new thickness direction is in the range 50% greater than the thickness dimension in said former thickness direction to 15% smaller than said thickness dimension in said former thickness direction.

14. Process according to claim 10 wherein in said step (b), there is performed a thickness reduction in the range of 10 to 50%.

15. Process according to any one of claims 1 to 14 wherein the aluminum alloy is an alloy of the AA 2000 or AA 7000 series.

16. Process according to claim 15 wherein the aluminum alloy is selected from the group consisting of AA 7010, AA 7049, AA 7149, AA 7050, AA 7150, AA 7055, AA 7064, AA 7075, AA 7175, AA 7475, AA 7076 and AA 7178.

17. Process according to claim 15 or claim 16 wherein the aluminum alloy contains by weight 5-9% Zn, 0.3-3% Cu, 1-3% Mg, max. 0.4% Si, max. 0.6% Fe, max. 0.5% Mn, max. 0.3% Zr, max. 0.3% Cr, max. 0.3% V, max. 0.3% Nb, max. 0.3% Hf and max. 0.5% Sc, remainder Al and inevitable impurities.

18. Thick aluminum alloy plate manufactured by a process according to any one of claims 1 to 17 wherein said manufactured plate has a thickness in the range of 2 to 12 inches (5 to 30 cm) and a log-average fatigue life at 35 ksi of at least 150 kcycles.

19. Thick aluminum alloy plate according to claim 18 having a log-average fatigue life at 35 ksi of at least 300 kcycles.

20. Thick aluminum alloy plate according to claim 18 or 19 having a thickness in the range of 6 to 12 inches (15 to 30 cm).

21. Thick aluminum alloy plate manufactured according to any one of claims 1 to 17 wherein said manufactured plate has a thickness in the range of 2 to 12 inches (5 to 30 cm) and a fracture toughness relative to its thickness as given by the following formula:

$$K_{Ic} (T - L) \geq - 1.2 \times G + 31.2$$

in which  $K_{Ic} (T - L)$  is the fracture toughness in the long transverse direction expressed in ksi inch<sup>0.5</sup> and G is the thickness of the plate expressed in inches.

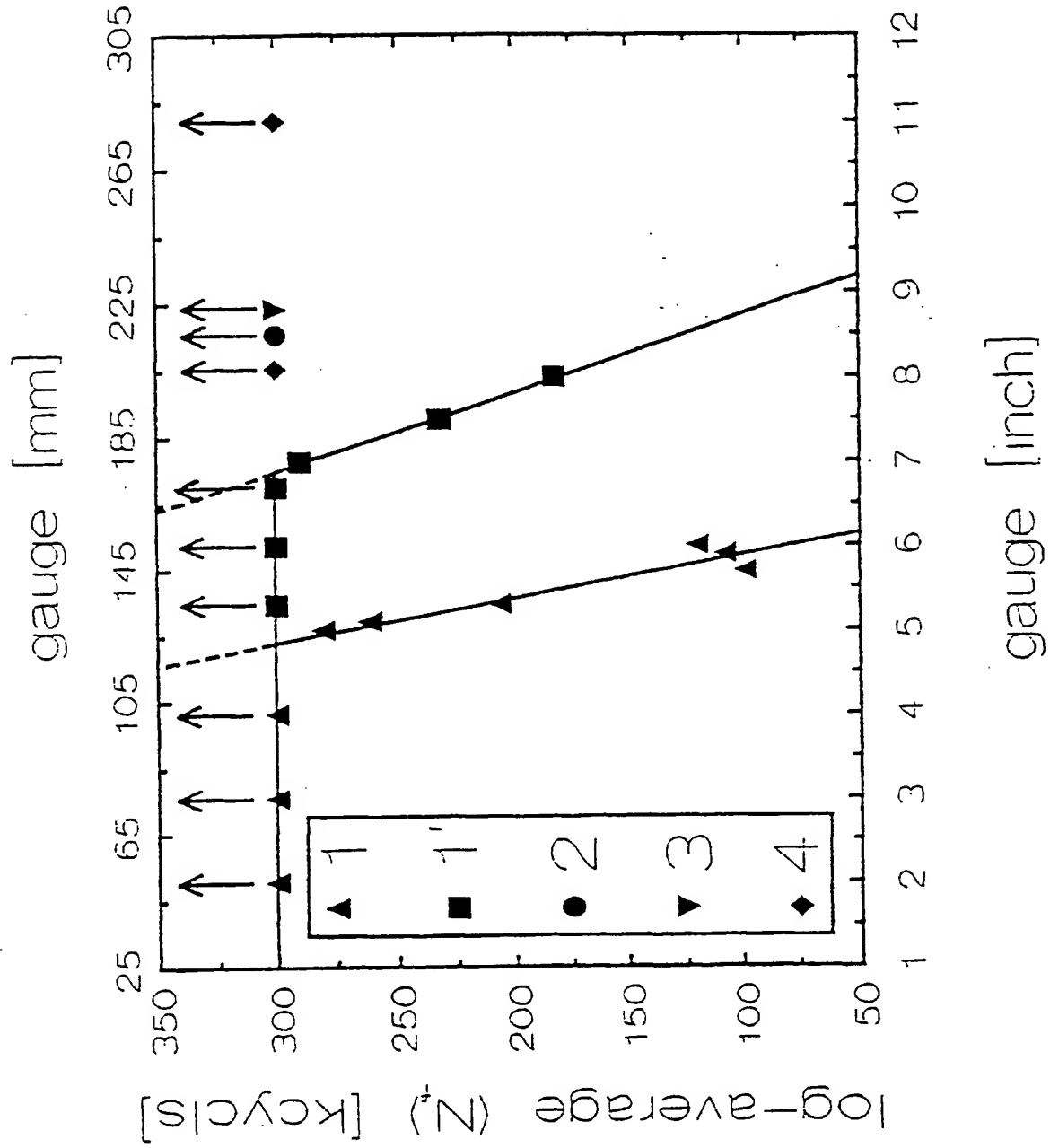


Fig. 1

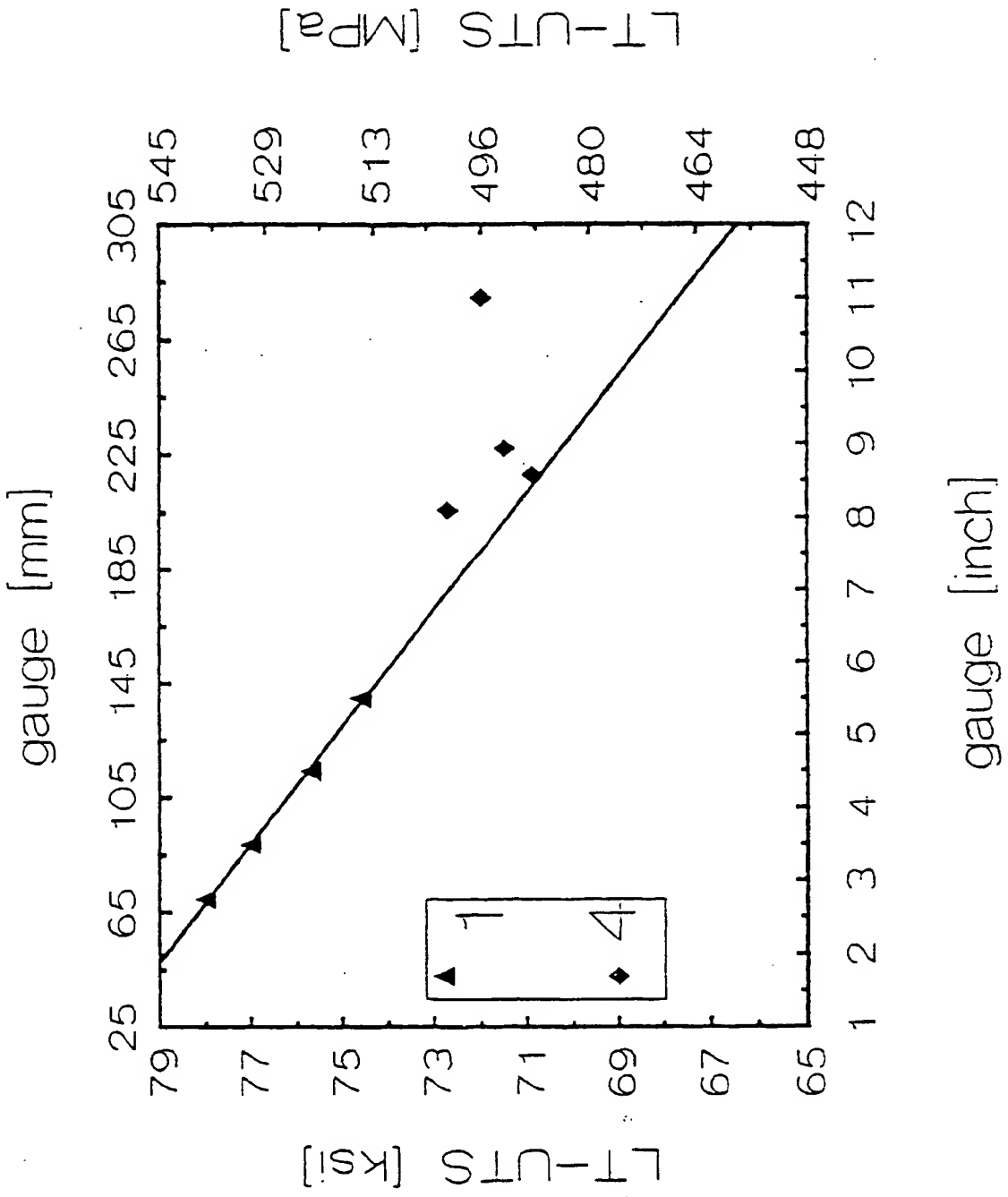


Fig. 2



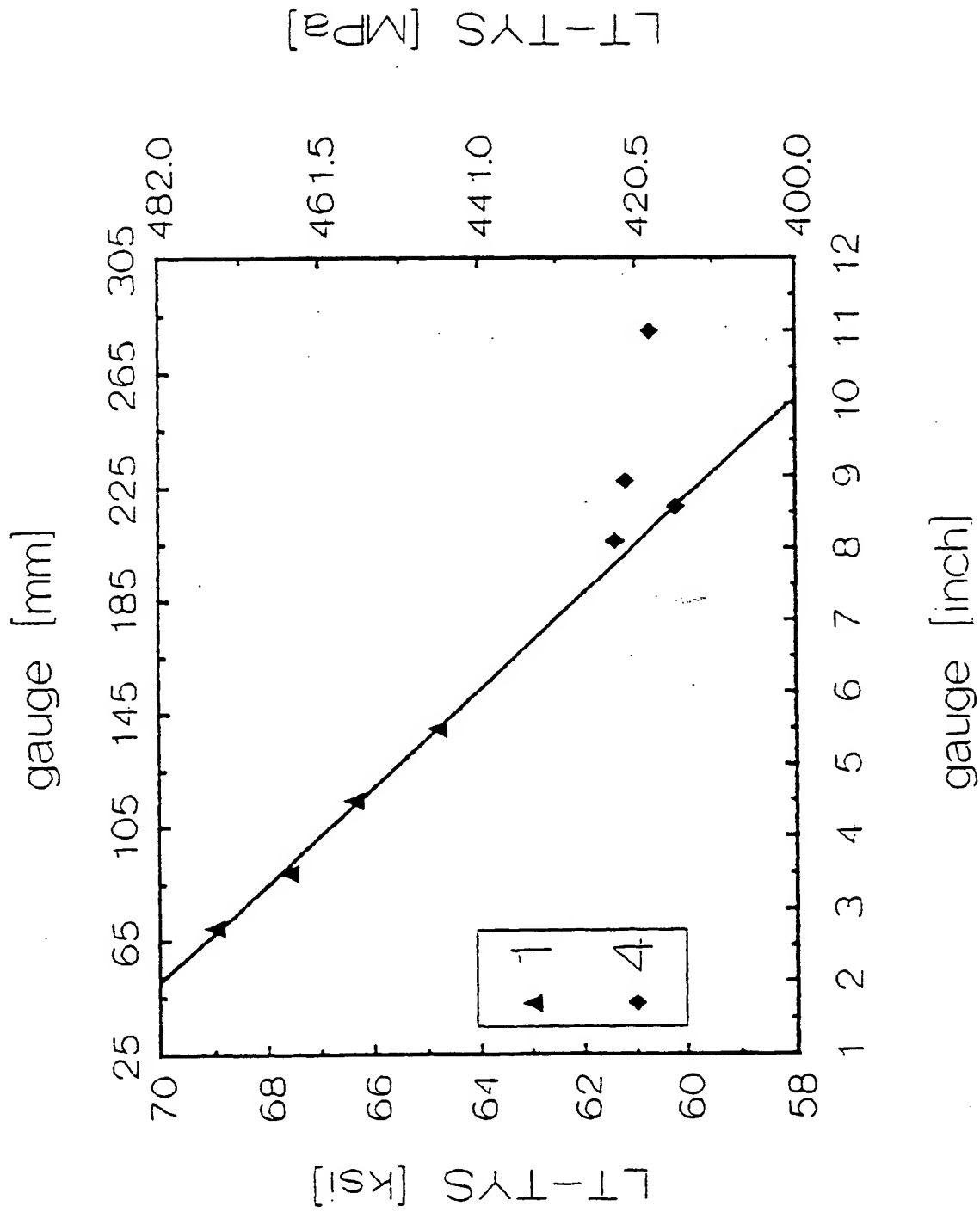


Fig. 3

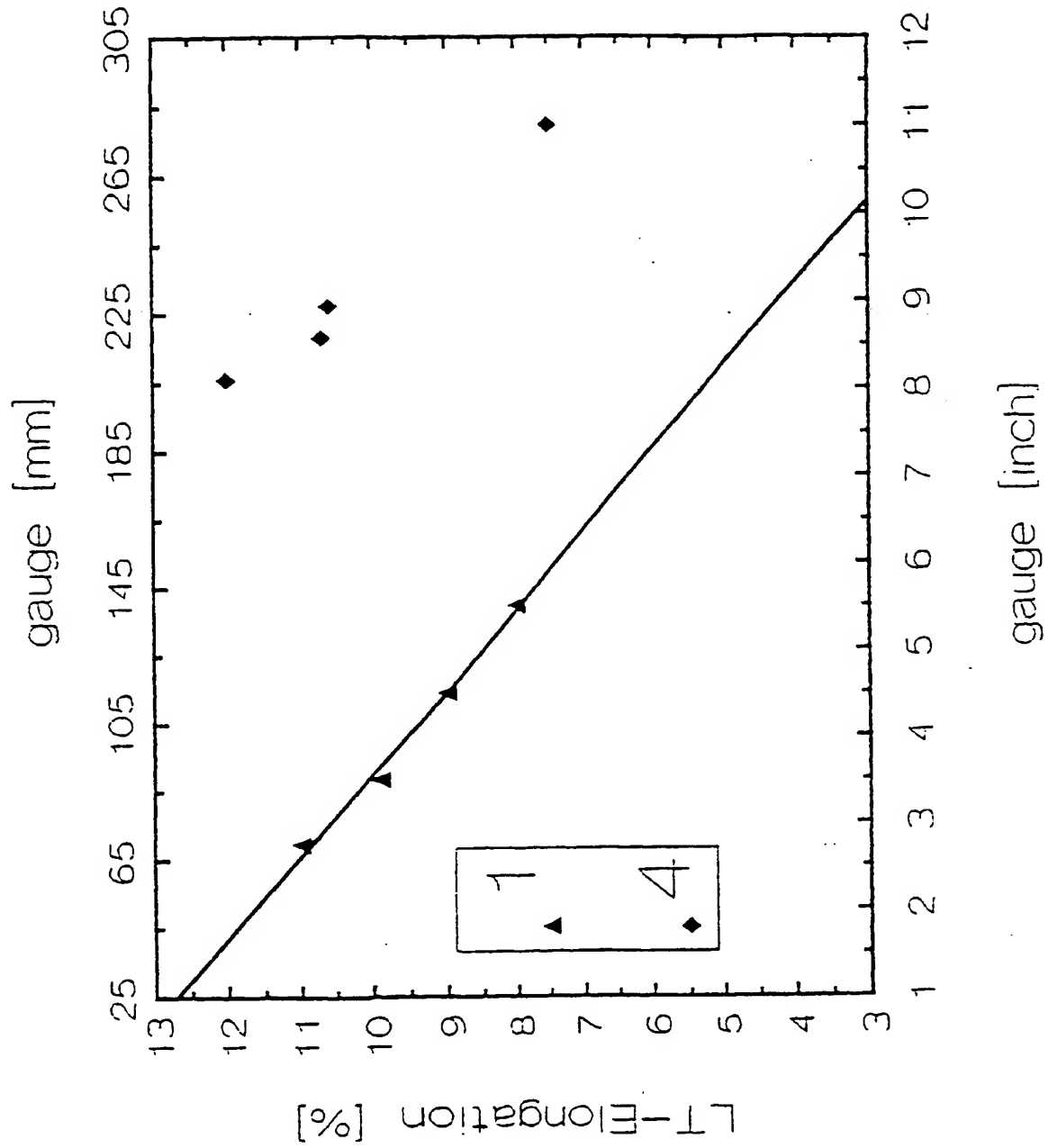


Fig. 4

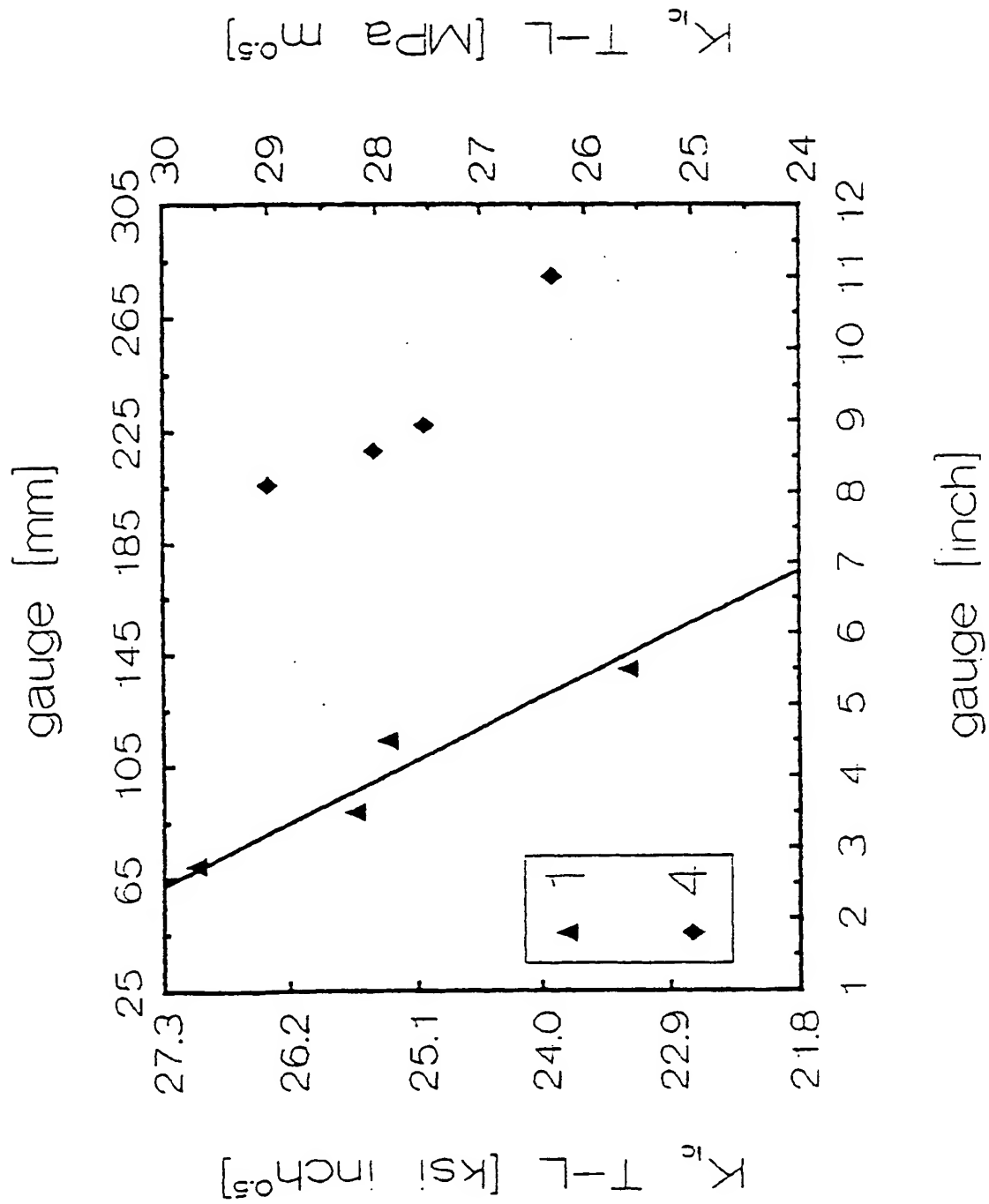


Fig. 5



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# EUROPEAN SEARCH REPORT

Application Number  
EP 96 20 0060

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
D,A	US-A-5 277 719 (KUHLMAN G WILLIAM ET AL) 11 January 1994 * column 3, line 49 - line 64 * * column 4, line 33 - line 49; claims 1,5,8 *	1,2	C22F1/04 C22F1/043
A	FR-A-2 529 578 (CEGEDUR) 6 January 1984 ---		
A	US-A-4 721 537 (GHOSH AMIT K) 26 January 1988 -----		
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			C22F
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 15 April 1996	Examiner Gregg, N
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